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THE MEASUREMENT OF AERODYNAMIC FORCES ON AN OSCILLATING MODEL OF A FAN-ENGINE NACELLE

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SUMMARY

A technique has been developed to measure the aerodynamic forces that are generated when a model fan-engine nacelle is oscillated in a uniform airflow. The technique enables the model to be oscillated in pitch or in yaw about one of two axis positions. A series of measurements for the four combinations of axis position and direction can be analysed to yield the aerodynamic stiffness and damping derivatives for motions of pitch, yaw, vertical and lateral translation.

A preliminary series of tests has been made using a simple model of a fan-engine in a low speed wind tunnel.

This Memorandum describes the rig and test technique, and discusses the outcome of the tests.

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CONTENTS

1 INTRODUCTION

Study of the flutter of wings carrying concentrated or localised masses has exercised the aeroelastician for 30 years or more. The literature is considerable, and Ref.1 summarises much of the early work up to 1960. Most of that work was concerned with wings to which an added mass was rigidly attached, and it was assumed, either explicitly or implicitly, that the aerodynamic effects of the shape of the mass would be small. In more recent years, the aero-elastician has had to deal with wing-mass systems in which there is significant flexibility between the wing and the added mass. Some of the earlier studies had indicated the importance of flexibility in the mass attachment system, and Ref.2 showed that large reductions in wing flutter speed could occur under certain conditions.

The development of the large fan-engine has introduced several new factors into the study of wing flutter. In the first place, the size of the engine relative to the wing is much greater than that of more 'conventional' added masses such as fuel tanks, equipment pods and underwing weapons. As a result, the aerodynamic forces associated with the fan-engine are relatively greater. Secondly, the engine is often pylon-mounted, and the inertias of the engine combine with the flexibility of the pylon to produce suspension frequencies that cannot be ignored in relation to wing flutter. Thirdly, the large fan diameter leads to large gyroscopic forces, making the flutter problem similar to the propeller-whirl problems that were important for some propeller-driven aircraft[3]. Fourthly, the mass flow of air through the engine is likely to be a significant parameter in relation to the aerodynamic forces, and, lastly, the aerodynamic forces on the wing are likely to be affected by the proximity of a large engine, and perhaps also by relative oscillatory motion between the two bodies.

In order to take account of these factors in predicting the flutter characteristics of a new aircraft, it is necessary to have a knowledge of the aerodynamic forces to be associated with oscillatory motions of the engine. Theory, in this area, is far from adequate, and much reliance has to be placed on the limited experimental evidence that has been obtained. Nearly all of this is unpublished, but Rainey[4], in 1968, referred to work at NASA in which aero-dynamic derivatives were measured for a series of model engines with a wind-milling fan. Subsequent work showed that the ratio of length to diameter of the cowl surrounding the fan could have an important bearing on the flutter characteristics of a typical wing-engine combination, because of the changes in

aerodynamic derivatives resulting from the change of cowl geometry. More recently, a joint RAE/ONERA wind tunnel research programme demonstrated, using an engine model in the form of concentric ducts (with no fan) that the flutter properties of the wing were significantly affected by the aerodynamic properties of the engine nacelle[5].

It is clear that there is a need for a more comprehensive programme of experimental work on the oscillatory aerodynamics of fan-engines, and, certainly from the designer's point of view there is a corresponding need for a valid aerodynamic theory which can be used in the design stage of a new aircraft.

A programme of experimental work was started at RAE aimed primarily at developing a technique for wind tunnel measurement of oscillatory aerodynamic derivatives on models of fan engines. A method of test was devised to enable a complete set of aerodynamic derivatives (both direct and 'cross' terms) to be found for pitch, yaw, vertical and lateral translation of the engine. The method has been applied to a simple model of a fan engine operating in a wind tunnel at low forward speed.

This Memorandum describes the development work that has been undertaken, and discusses the results of the preliminary tests and the rig modifications indicated.

It is concluded that the technique is generally satisfactory for stiffness derivatives, but that the sensitivity of the force measuring system needs improvement to obtain consistent results. It may not be possible to effect sufficient improvement to enable damping derivatives to be measured.

Due to staff redeployment this work has now ceased at the RAE, but it is hoped that it will be continued at the University of Bristol who have taken over the rig.

2 TEST TECHNIQUES

2.1 Test requirements

Consider a set of axes, shown in Fig.1, in which the origin is at the centre of the fan. The aerodynamic forces F_Y and F_Z along the Y and Z axes, and the aerodynamic moments M_Y and M_Z about these axes may be written:

$$\begin{bmatrix} \frac{2F_Y}{S} \\ \frac{2F_Z}{S} \\ \frac{M_Y}{SR} \\ \frac{M_Z}{SR} \end{bmatrix} = \rho V^2 \begin{bmatrix} C_{Yy} & C_{Yv} & C_{Yz} & C_{Yw} & C_{Y\theta} & C_{Yq} & C_{Y\psi} & C_{Yr} \\ C_{Zy} & C_{Zv} & C_{Zz} & C_{Zw} & C_{Z\theta} & C_{Zq} & C_{Z\psi} & C_{Zr} \\ C_{My} & C_{Mv} & C_{Mz} & C_{Mw} & C_{M\theta} & C_{Mq} & C_{M\psi} & C_{Mr} \\ C_{Ny} & C_{Nv} & C_{Nz} & C_{Nw} & C_{N\theta} & C_{Nq} & C_{N\psi} & C_{Nr} \end{bmatrix} \begin{bmatrix} y/R \\ v/V \\ z/R \\ w/V \\ \theta \\ qR/V \\ \psi \\ -rR/V \end{bmatrix} \qquad \ldots\ldots (1)$$

where ρ is air density
V is axial velocity of air at fan disc
S is the area of the fan disc
R is the radius of the tip of a fan blade
y, z are displacements in the directions of the Y and Z axes
u, w are velocities in the directions of the Y and Z axes
θ, ψ are angular rotations about the Y and Z axes
q, r are angular velocities about the Y and Z axes

and a coefficient C_{ab} is associated with the force (or moment) in the direction 'a' due to motion in the direction 'b'. The suffices M and N denote moment coefficients about the Y and Z axes. Two examples will illustrate the notation: C_{Zv} is the coefficient of force along the Z axis due to velocity along the Y axis (i.e. lift due to lateral translational velocity); C_{Nr} is the coefficient of moment about the Z axis due to angular velocity about the Z axis (i.e. yawing moment due to yawing velocity).

The above notation has been widely used both in the UK and in the US, and there is no reason for adopting a different notation at this time. However, a slight modification of the notation enables the forces and moments to be expressed in a form that is more familiar to the flutter analyst, and simplifies equations (1).

For sinusoidal motion at circular frequency ω the forces and moments F_Y, F_Z, M_Y, M_Z and the motions y, z, θ and ψ may be regarded as amplitudes and v/V, w/V, qR/V and rR/V may be replaced by $i\nu y/R$, $i\nu z/R$, $i\nu\theta$ and $i\nu\psi$ respectively, where ν, a non-dimensional frequency parameter, is defined as $\omega R/V$.

If equation (1) is expanded, pairs of terms are obtained such as

$$C_{Yy}\frac{y}{R} + C_{Yv}\frac{v}{V} \quad \text{and} \quad C_{M\theta}\theta + C_{Mq}\frac{qR}{V} \quad .$$

These may now be rewritten as

$$\frac{y}{R}(C_{Yy} + i\nu C_{Yv}) \quad \text{and} \quad \theta(C_{M\theta} + i\nu C_{Mq}) \quad .$$

The first term in each bracket will be recognised as an aerodynamic stiffness term and the second as an aerodynamic damping term. It is convenient to let

$$(C_{Yy} + i\nu C_{Yv}) = \bar{C}_{Yy}$$

$$(C_{M\theta} + i\nu C_{Mq}) = \bar{C}_{M\theta} \qquad \text{etc.}$$

and equations (1) can then be written

$$\begin{bmatrix} \frac{2F_Y}{S} \\ \frac{2F_Z}{S} \\ \frac{M_Y}{SR} \\ \frac{M_Z}{SR} \end{bmatrix} = \rho V^2 \begin{bmatrix} \bar{C}_{Yy} & \bar{C}_{Yz} & \bar{C}_{Y\theta} & \bar{C}_{Y\psi} \\ \bar{C}_{Zy} & \bar{C}_{Zz} & \bar{C}_{Z\theta} & \bar{C}_{Z\psi} \\ \bar{C}_{My} & \bar{C}_{Mz} & \bar{C}_{M\theta} & \bar{C}_{M\psi} \\ \bar{C}_{Ny} & \bar{C}_{Nz} & \bar{C}_{N\theta} & \bar{C}_{N\psi} \end{bmatrix} \begin{bmatrix} \frac{y}{R} \\ \frac{z}{R} \\ \theta \\ \psi \end{bmatrix} \quad . \qquad (2)$$

In order to determine the 16 complex $\bar{C}$ coefficients it is clearly necessary to measure the four (complex) forces and moments F_Y, F_Z, M_Y and M_Z for each of four linearly independent combinations of the motions y/R, z/R, θ and ψ . Denoting each set of measurements and motions by suffices 1 ... 4, equations (2) can then be expressed as

$$[F'] = \rho V^2 [C] [\beta] \qquad (3)$$

from which

$$[C] = \frac{1}{\rho V^2} [F'] [\beta]^{-1} \qquad (4)$$

where

$$F' = \begin{bmatrix} \frac{2F_{Y1}}{S} & \frac{2F_{Y2}}{S} & \frac{2F_{Y3}}{S} & \frac{2F_{Y4}}{S} \\ \frac{2F_{Z1}}{S} & \frac{2F_{Z2}}{S} & \frac{2F_{Z3}}{S} & \frac{2F_{Z4}}{S} \\ \frac{M_{Y1}}{SR} & \frac{M_{Y2}}{SR} & \frac{M_{Y3}}{SR} & \frac{M_{Y4}}{SR} \\ \frac{M_{Z1}}{SR} & \frac{M_{Z2}}{SR} & \frac{M_{Z3}}{SR} & \frac{M_{Z4}}{SR} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \frac{y_1}{R} & \frac{y_2}{R} & \frac{y_3}{R} & \frac{y_4}{R} \\ \frac{z_1}{R} & \frac{z_2}{R} & \frac{z_3}{R} & \frac{z_4}{R} \\ \theta_1 & \theta_2 & \theta_3 & \theta_4 \\ \psi_1 & \psi_2 & \psi_3 & \psi_4 \end{bmatrix}$$

and C is the square matrix of $\bar{C}$ coefficients.

In designing an experiment to measure the $\bar{C}$ coefficients, one is restricted by practical considerations. For example, it is never easy to design a rig which will constrain a body to oscillate freely in pure translation, and it is not, therefore, feasible to impose motions that will lead to a diagonal β matrix. However, it is relatively easy to impose rotational motions, and if two axes of rotation are chosen in the same sense (i.e. two pitch or two yaw axes) each motion will be a linearly independent combination of rotation and translation. For reasons of economy and simplicity, it is also desirable that the same test rig should be used for (i) pitch and vertical translation, and (ii) yaw and lateral translation. From these considerations, a rig was designed which allows the model fan-engine to be oscillated in pitch or in yaw about two axes - a total of four arrangements. (The change from pitch to yaw is effected by rotating the whole rig through 90° on its stand.) The geometry of the system is shown diagrammatically in Fig.2. It can be seen that the four arrangements lead to the following relationships:

$$\left.\begin{array}{llll}
\text{test 1:} & \text{pitching about axis 1:} & z_1 = -d_1\theta_1 \;, & y_1 = \psi_1 = 0 \\
\text{test 2:} & \text{pitching about axis 2:} & z_2 = -d_2\theta_2 \;, & y_2 = \psi_2 = 0 \\
\text{test 3:} & \text{yawing about axis 3:} & y_3 = d_1\psi_3 \;, & z_3 = \theta_3 = 0 \\
\text{test 4:} & \text{yawing about axis 4:} & y_4 = d_2\psi_4 \;, & z_4 = \theta_4 = 0
\end{array}\right\} \quad (5)$$

and the β matrix is therefore

$$\beta = \begin{bmatrix} 0 & 0 & \dfrac{d_1\psi_3}{R} & \dfrac{d_2\psi_4}{R} \\ -\dfrac{d_1\theta_1}{R} & -\dfrac{d_2\theta_2}{R} & 0 & 0 \\ \theta_1 & \theta_2 & 0 & 0 \\ 0 & 0 & \psi_3 & \psi_4 \end{bmatrix} . \quad (6)$$

Obviously, it is not necessary to obtain all the terms of the F' matrix before evaluating the $\bar{C}$ coefficients. Although there are 16 equations represented by the matrix equation (4), they can be taken four at a time to solve for the four coefficients associated with, say, F_Y , and because of equations (5), they can be taken as two separate pairs, e.g.

$$\frac{2F_{Y1}}{S} = \rho V^2\left(-\bar{C}_{Yz}\frac{d_1\theta_1}{R} + \bar{C}_{Y\theta}\theta_1\right)$$

$$\frac{2F_{Y2}}{S} = \rho V^2\left(-\bar{C}_{Yz}\frac{d_2\theta_2}{R} + \bar{C}_{Y\theta}\theta_2\right) ,$$

from which

$$\left.\begin{array}{l}
\bar{C}_{Yz} = \dfrac{-R}{\frac{1}{2}\rho V^2 S}\left(\dfrac{F_{Y1}}{\theta_1} - \dfrac{F_{Y2}}{\theta_2}\right)\dfrac{1}{(d_1 - d_2)} = C_{Yz} + i\nu C_{Yw} \\
\text{and} \\
\bar{C}_{Y\theta} = \dfrac{-1}{\frac{1}{2}\rho V^2 S}\left(-\dfrac{F_{Y1}d_2}{\theta_1} + \dfrac{F_{Y2}d_1}{\theta_2}\right)\dfrac{1}{(d_1 - d_2)} = C_{Y\theta} + i\nu C_{Yq}
\end{array}\right\} \quad (7)$$

and

$$\frac{2F_{Y3}}{S} = \rho V^2\left(C_{Yy}\frac{d_1\psi_3}{R} + C_{Y\psi}\psi_3\right)$$

$$\frac{2F_{Y4}}{S} = \rho V^2\left(C_{Yy}\frac{d_2\psi_4}{R} + C_{Y\psi}\psi_4\right)$$

from which

$$\left.\begin{aligned} \bar{C}_{Yy} &= \frac{R}{\frac{1}{2}\rho V^2 S}\left(\frac{F_{Y3}}{\psi_3} - \frac{F_{Y4}}{\psi_4}\right)\frac{1}{(d_1 - d_2)} = C_{Yy} + i\nu C_{Yv} \\ \text{and} \\ \bar{C}_{Y\psi} &= \frac{1}{\frac{1}{2}\rho V^2 S}\left(-\frac{F_{Y3}d_2}{\psi_3} + \frac{F_{Y4}d_1}{\psi_4}\right)\frac{1}{(d_1 - d_2)} = C_{Y\psi} + i\nu C_{Yr} \end{aligned}\right\} . \tag{8}$$

Similar expressions are found for the other derivatives; these are given in the Appendix.

For the case of an engine on an aircraft, the proximity of the wing and pylon may give different values for the derivatives due to motion in the lateral and vertical directions; however for an axisymmetric system, coefficients relating to vertical translation and pitch will be numerically equal to those relating to lateral translation and yaw. Thus:

$$\left.\begin{aligned} C_{Zy} &= -C_{Yz} & C_{My} &= C_{Nz} \\ C_{Zz} &= C_{Yy} & C_{Mz} &= -C_{Ny} \\ C_{Z\theta} &= -C_{Y\psi} & C_{M\theta} &= C_{N\psi} \\ C_{Z\psi} &= C_{Y\theta} & C_{M\psi} &= -C_{N\theta} \end{aligned}\right\} \tag{9}$$

for an axisymmetric system, the negative signs arising from the axis notation.

2.2 Test rig

The basic rig, to which nacelles of various geometry can be attached, is shown diagrammatically in Fig.2. The main framework consists of two parallel steel plates AA" and BB" of rectangular cross-section which are joined by two shorter plates AB and A'B' leaving an overhang at A" and B" .

A U-shaped frame is pivoted to the main frame to give it rotational freedom about axes LL' or KK' . A drive-shaft to the fan is carried in bearings in a housing on the front of the U-frame, and this shaft fits into a universal joint on the line of the rotational axis KK' . Another shaft joins this to a second joint on axis LL' and a shaft runs from this point through a bearing in the plate A'B' to a motor which is mounted between the plates AA' and BB' . The two universal joints allow relative angular motion between the shafts, whilst transmitting torque with negligible load transmission in other directions. The arrangement allows the fan, and any structure attached to the U-frame, to be oscillated about the chosen pivot axis whilst the fan is driven. The bearing housing on the front of the U-frame is fitted with strain-gauges to measure the forces and moments applied to the U-frame (Fig.3). It follows that any part of the oscillating system for which force and moment measurements are required must be attached to the bearing housing so that the strain gauges lie between these parts and the U-frame. When this is done, the only remaining path for force and moment transmission between the oscillating model and the support structure is along the drive shaft, and these forces and moments are designed to be eliminated by the universal joints in the shaft at the pivot axes.

The pivots themselves are commercially-made cross-spring units which are plugged into the holes at LL' or KK' . One of the units is strain gauged so that it acts as an angular displacement transducer (Fig.4).

An electromagnetic exciter is used to oscillate the front part of the rig, and is mounted between the steel plates AA' and BB' to the rear of the motor. The exciter coil is carried on the end of an arm attached to the front U-frame (Fig.5).

The rig is enclosed by detachable streamline fairings. There is a gap in the fairing, level with the pivot position, to allow relative movement; the gap is covered by a thin rubber strip. Two sets of fairings allow for the two different pivot positions. The front part of the fairing is attached to the bearing housing as are the four struts which carry the engine duct. Thus the whole of the 'engine' part of the rig is mounted on the force measuring system.

The four struts, which are made of carbon fibre in order to give a high stiffness/mass ratio, are attached to the rear part of the engine duct (Fig.6), and the three interchangeable front cowls are screwed to this (Fig.7). The duct is mainly made of balsa wood. A scale profile drawing of the model is shown in Fig.8.

The fan used in these preliminary tests is an eight-bladed nylon car radiator unit chosen for its ready availability rather than for technical reasons.

Tests were also made without the fan, and for these an aluminium alloy disc was substituted having the same outside dimensions as the fan hub and the same moments of inertia as the fan.

The rig is mounted on two tubular steel stands on which it has a fundamental resonance frequency of approximately 25Hz. The illustrations all show the rig mounted so that the engine nacelle moves horizontally and all the preliminary tests were made in this configuration. However provision is made in the design for an alternative mounting of the rig on its stands whereby the nacelle can be oscillated vertically. The whole rig is rotated through 90° and attached to the stands by adaptor pieces with the exciter arm on the upper side of the rig. The alternative mountings are only likely to be needed if the model is tested in conjunction with a wing when the assumption of axisymmetry is no longer valid.

2.3 Excitation and drive

Since the pivot for the model engine is behind the duct, it is likely that the model will diverge when the wind tunnel is running. To avoid this, a position servo system is used. A signal from the strain-gauged cross-spring pivot indicates the model position, and this is fed into a summing amplifier together with a demand signal from an oscillator. The output then goes to a power amplifier driving the electromagnetic exciter (Fig.9). The system has shown itself capable of giving the desired motion of the model under all tunnel conditions.

The fan is driven by a high frequency induction motor powered from a 400Hz, 3-phase, supply. The motor is water cooled and is capable of producing 5.5kW at 13000rev/min.

2.4 Instrumentation

The engine model, comprising the outer duct, the four support struts, the fan and the inner fairing, is connected to the U-frame by a thin walled cylindrical steel shell (Fig.3). This is strain-gauged to measure yawing moment, pitching moment, vertical force and lateral force. The moments are about axes passing through the gauges on the shell, which is some distance behind the fan, and in order to obtain the desired moments about the fan itself after

amplification, a proportion of the appropriate force signal is electronically added to each moment signal. The four force and moment signals and the position signal from the strain-gauged cross-spring pivot then pass through a selector switch to a resolved component indicator. This instrument displays the in-phase and quadrature components of the signal relative to a reference signal from the oscillator. The oscillator is designed so that the phase of this reference signal can be changed relative to the output to the servo system (Fig.9).

Airspeed through the engine duct is measured by a small anemometer mounted just inside the trailing edge of the duct; it consists of a two-bladed fan whose rotational speed is measured electronically. The engine fan speed is given by a tachometer built into the electric motor.

2.5 Test procedure

The force measuring system was calibrated statically by hanging weights from the fan shaft. It was not considered necessary to calibrate with oscillatory loads since the natural frequency of the force measuring system was of the order of 1kHz and its transfer function was therefore flat at the frequencies at which the rig was operating. The strain-gauged pivot was also calibrated statically using an inclinometer.

The anemometer was calibrated off the rig by mounting it in the wind tunnel and taking readings at various tunnel speeds.

The tests were made in the RAE 5ft wind tunnel. The procedure for each test condition was as follows. When the tunnel and fan speeds had been set, the oscillator was switched on to excite the model. The angular displacement signal was switched to the resolved component indicator, and the phase between the two oscillator outputs was adjusted until the signal showed no quadrature component. The amplitude of the oscillator signal was then set to give the desired vibration amplitude. This setting-up procedure meant that subsequent measurements of the forces and moments on the resolved component indicator gave in-phase and quadrature results directly, relative to the model motion.

The in-phase and quadrature components of vertical and lateral force and pitching and yawing moment were measured for each test condition twice, once with the front engine pivots installed and once with the rear.

Since no wing or pylon was involved in these tests, yaw and pitch were equivalent and the model was only tested in yaw.

Because the tests were intended mainly to try out the rig and because time in the wind tunnel was limited, it was not possible to carry out a comprehensive investigation of the way the derivatives varied with the various parameters such as Reynolds number, frequency parameter and thrust. In fact, for reasons detailed in section 3, the tests were all made with an excitation frequency of 10Hz and with a fan or disc speed of 3000rev/min, and at one of five different tunnel speeds. It should be noted however that even this limited investigation involved taking about 1000 measurements, each of which took over a minute to make.

To study the way the derivatives vary with all the parameters, a full series of tests would have to be made at various excitation frequencies and fan speeds as well as at different tunnel speeds. The way in which it was intended to separate out the various effects is explained in the next section.

3 TEST FINDINGS

For each combination of tunnel speed and duct length, tests were made with either the fan or the disc fitted and with these either stationary or running at 3000rev/min. The tunnel speeds ranged from zero to 61m/s (200ft/s).

The forces due to the inertia of the model were to be obtained from the zero tunnel speed, and zero fan (or disc) speed, tests. Gyroscopic forces were given by the zero tunnel speed tests with the disc fitted. The results from these tests could then be subtracted from the other test results to give the aerodynamic contributions.

Since many of the aerodynamic forces generated are small in comparison with the inertia and gyroscopic forces, and since equations (7) are taking small differences between relatively large quantities, it is obviously vital to make the force measurements as accurately as possible. In practice it was found that in some cases a 1% change in one of the original measurements could produce a 20% change in the value of the calculated derivatives.

In fact the sensitivity of the force measuring system did not enable the measurements to be made with sufficient accuracy to obtain values of stiffness derivatives with the required degree of repeatability, and it was totally inadequate for obtaining sensible values for the damping derivatives. These derivatives were found from the quadrature components of the forces which (apart from the gyroscopic contributions) were small compared to the in-phase components. Thus small errors in setting the phase of the oscillator would produce large errors in the derivatives.

Two other problems became apparent during initial testing of the rig. Firstly the fan, which was designed for low forward speeds, was incapable of producing thrust at the higher tunnel speeds, and secondly the fundamental natural frequency of the rig on its stand was not high enough to avoid unwanted motion of the model at high excitation frequencies.

These factors meant that it was not possible to vary systematically either the frequency parameter or the thrust.

Towards the end of the tests some problems were experienced with lubrication breakdown on the universal joints on the fan drive shaft. These had plain bearings, and the increase in friction showed itself in the form of large irregular force signals. These disappeared when the joint was re-oiled.

4 DISCUSSION

The tests showed up a number of deficiencies of the rig and test technique which need attention before further tests are made.

(i) The sensitivity of the force measuring system needs improving. This could be done by reducing the wall thickness of the strain-gauged cylinder (Fig.3) or constructing another from a lower modulus material. The use of semi-conductor strain gauges would also help, although problems of thermal drift might occur. It should be possible with these modifications to obtain an order of magnitude improvement in the sensitivity (and in the signal-to-noise ratio since most of the noise appeared to originate within the amplifiers) without reducing the natural frequency of the force measuring system enough to give problems.

(ii) The analysis of the signals could be made with more consistency using a digital system such as a Fourier analyser. This would also speed up the analysis since the phase setting-up procedure could be omitted, and the excitation of the model could be rapidly swept over a range of frequencies instead of analysing at discrete frequencies as was done in the initial tests.

(iii) A better fan is needed, preferably with variable pitch blades. Such fans are commercially available, and would enable systematic variation of the thrust to be made.

(iv) The stiffness of the support stand needs increasing. It might be possible to accomplish this by wire bracing of the rig in the wind tunnel.

(v) The universal joints on the drive shaft have been replaced since these tests by a type with needle-roller bearings and sealed-in lubrication.

Because of the limited scope of the tests and the shortcomings mentioned, no actual derivative results have been included in this Memorandum. It may be said, however, that such results as were obtained were broadly in agreement with those mentioned in Ref.4. This provides some confidence that, with the incorporation of the above modifications, the rig and technique will be capable of producing accurate results for the stiffness derivatives, although the damping derivatives may still give problems.

5 CONCLUSIONS

A technique and a rig for measuring the aerodynamic forces generated on an oscillating model fan-engine nacelle have been developed. A preliminary series of tests disclosed the need for various improvements before a full investigation of the derivatives is performed. Such results as were obtained for the stiffness derivatives appear to be in reasonable agreement with other available informa-information.

Further tests of the rig incorporating the suggested modifications should produce accurate results for the stiffness derivatives, but possibly not for the damping derivatives.

Appendix

DERIVATION OF COEFFICIENTS

$$\bar{C}_{Yy} = (C_{Yy} + i\nu C_{Yv}) = \frac{R}{\frac{1}{2}\rho V^2 S}\left(\frac{F_{Y3}}{\psi_3} - \frac{F_{Y4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Y\psi} = (C_{Y\psi} + i\nu C_{Yr}) = \frac{1}{\frac{1}{2}\rho V^2 S}\left(- d_4 \frac{F_{Y3}}{\psi_3} - d_3 \frac{F_{Y4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Yz} = (C_{Yz} + i\nu C_{Yw}) = \frac{-R}{\frac{1}{2}\rho V^2 S}\left(\frac{F_{Y1}}{\theta_1} - \frac{F_{Y2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{Y\theta} = (C_{Y\theta} + i\nu C_{Yq}) = \frac{-1}{\frac{1}{2}\rho V^2 S}\left(- d_2 \frac{F_{Y1}}{\theta_1} + d_1 \frac{F_{Y2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{Zy} = (C_{Zy} + i\nu C_{Zv}) = \frac{R}{\frac{1}{2}\rho V^2 S}\left(\frac{F_{Z3}}{\psi_3} - \frac{F_{Z4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Z\psi} = (C_{Z\psi} + i\nu C_{Zr}) = \frac{1}{\frac{1}{2}\rho V^2 S}\left(- d_4 \frac{F_{Z3}}{\psi_3} + d_3 \frac{F_{Z4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Zz} = (C_{Zz} + i\nu C_{Zw}) = \frac{-R}{\frac{1}{2}\rho V^2 S}\left(\frac{F_{Z1}}{\theta_1} - \frac{F_{Z2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{Z\theta} = (C_{Z\theta} + i\nu C_{Zq}) = \frac{-1}{\frac{1}{2}\rho V^2 S}\left(- d_2 \frac{F_{Z1}}{\theta_1} + d_1 \frac{F_{Z2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{My} = (C_{My} + i\nu C_{Mv}) = \frac{1}{\rho V^2 S}\left(\frac{M_{Y3}}{\psi_3} - \frac{M_{Y4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{M\psi} = (C_{M\psi} + i\nu C_{Mr}) = \frac{1}{\rho V^2 SR}\left(- d_4 \frac{M_{Y3}}{\psi_3} + d_3 \frac{M_{Y4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Mz} = (C_{Mz} + i\nu C_{Mw}) = \frac{-1}{\rho V^2 S}\left(\frac{M_{Y1}}{\theta_1} - \frac{M_{Yz}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{M\theta} = (C_{M\theta} + i\nu C_{Mq}) = \frac{-1}{\rho V^2 SR}\left(- d_2 \frac{M_{Y1}}{\theta_1} + d_1 \frac{M_{Y2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{Ny} = (C_{Ny} + i\nu C_{Nv}) = \frac{1}{\rho V^2 S}\left(\frac{M_{Z3}}{\psi_3} - \frac{M_{Z4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{N\psi} = (C_{N\psi} + i\nu C_{Nr}) = \frac{1}{\rho V^2 SR}\left(- d_4 \frac{M_{Z3}}{\psi_3} + d_3 \frac{M_{Z4}}{\psi_4}\right)\left(\frac{1}{d_3 - d_4}\right)$$

$$\bar{C}_{Nz} = (C_{Nz} + i\nu C_{Nw}) = \frac{1}{\rho V^2 S}\left(\frac{M_{Z1}}{\theta_1} - \frac{M_{Z2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

$$\bar{C}_{N\theta} = (C_{N\theta} + i\nu C_{Nq}) = \frac{1}{\rho V^2 SR}\left(- d_2 \frac{M_{Z1}}{\theta_1} + d_1 \frac{M_{Z2}}{\theta_2}\right)\left(\frac{1}{d_1 - d_2}\right)$$

Test 1: pitching about axis 1: $z_1 = d_1\theta_1$, $y_1 = \psi_1 = 0$

Test 2: pitching about axis 2: $z_2 = d_2\theta_1$, $y_2 = \psi_2 = 0$

Test 3: yawing about axis 3: $y_3 = d_3\psi_3$, $z_3 = \theta_3 = 0$

Test 4: yawing about axis 4: $y_4 = d_4\psi_4$, $z_4 = \theta_4 = 0$.

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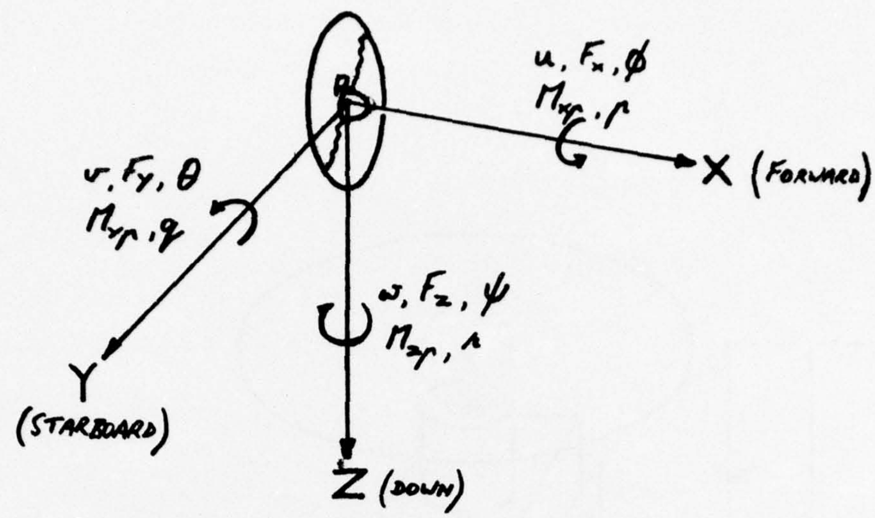
No.	Author	Title, etc.
1	D.R. Gaukroger	Wing flutter. AGARD Manual on Aeroelasticity, Part V, Chapter 2 (1960)
2	D.R. Gaukroger	Flutter characteristics of a wing carrying a flexibly mounted mass. R&M 3330 (1963)
3	J. Houbolt W.H. Reed	Propeller-nacelle whirl flutter. J. Aero. Sci. 29 (3): 333-346 (1962)
4	A.G. Rainey	Aeroelastic considerations for transports of the future - subsonic, supersonic and hypersonic. AIAA 'Aircraft design for 1980 operations' Meeting, AIAA No.68-215 (1968)
5	D.A. Drane G.B. Hutton	Wind tunnel flutter tests at subsonic speeds on a half-wing with a fan engine nacelle. RAE Technical Report 74130 (1974)



AXES:	X	Y	Z
DIRECTION:	FORWARD	STARBOARD	DOWN
ROTATIONS:	ϕ	θ	ψ
DESCRIBED:	ROLL	PITCH	YAW
DIRECTION:	STBD. DOWN	NOSE UP	NOSE STBD.
VELOCITIES:	u	v	w
ANGULAR VELOCITIES:	p	q	r
FORCES:	F_x	F_Y	F_Z
MOMENTS:	M_x	M_Y	M_Z
FORCE DERIVATIVES:	C_{x-}	C_{Y-}	C_{Z-}
MOMENT DERIVATIVES:		C_{M-}	C_{N-}

Fig.1 Notation and axis conventions

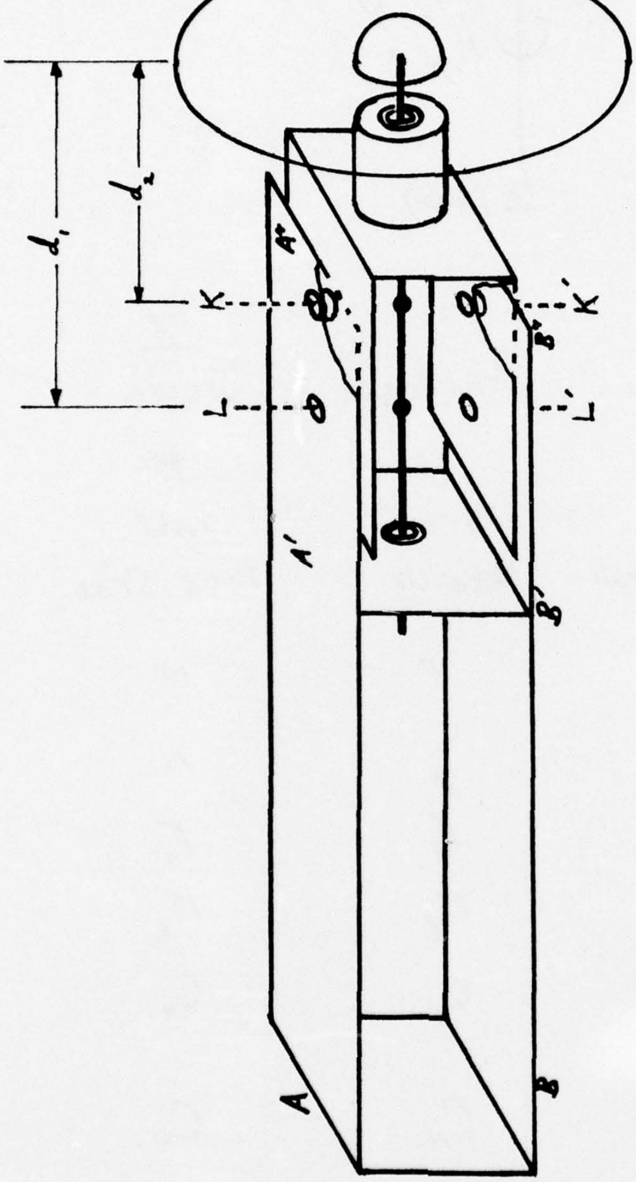


Fig.2 Diagram of test rig

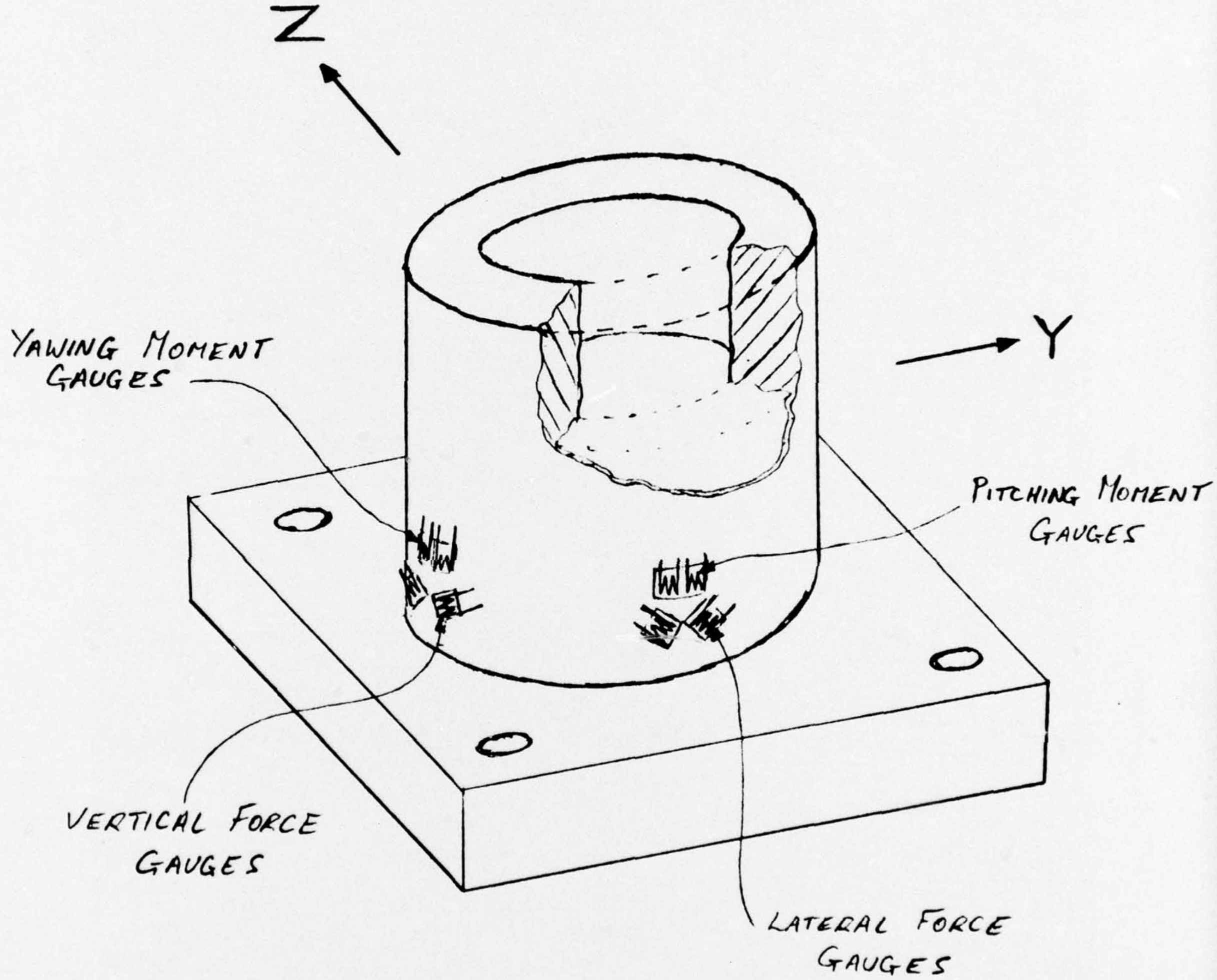


Fig.3 Force measuring system

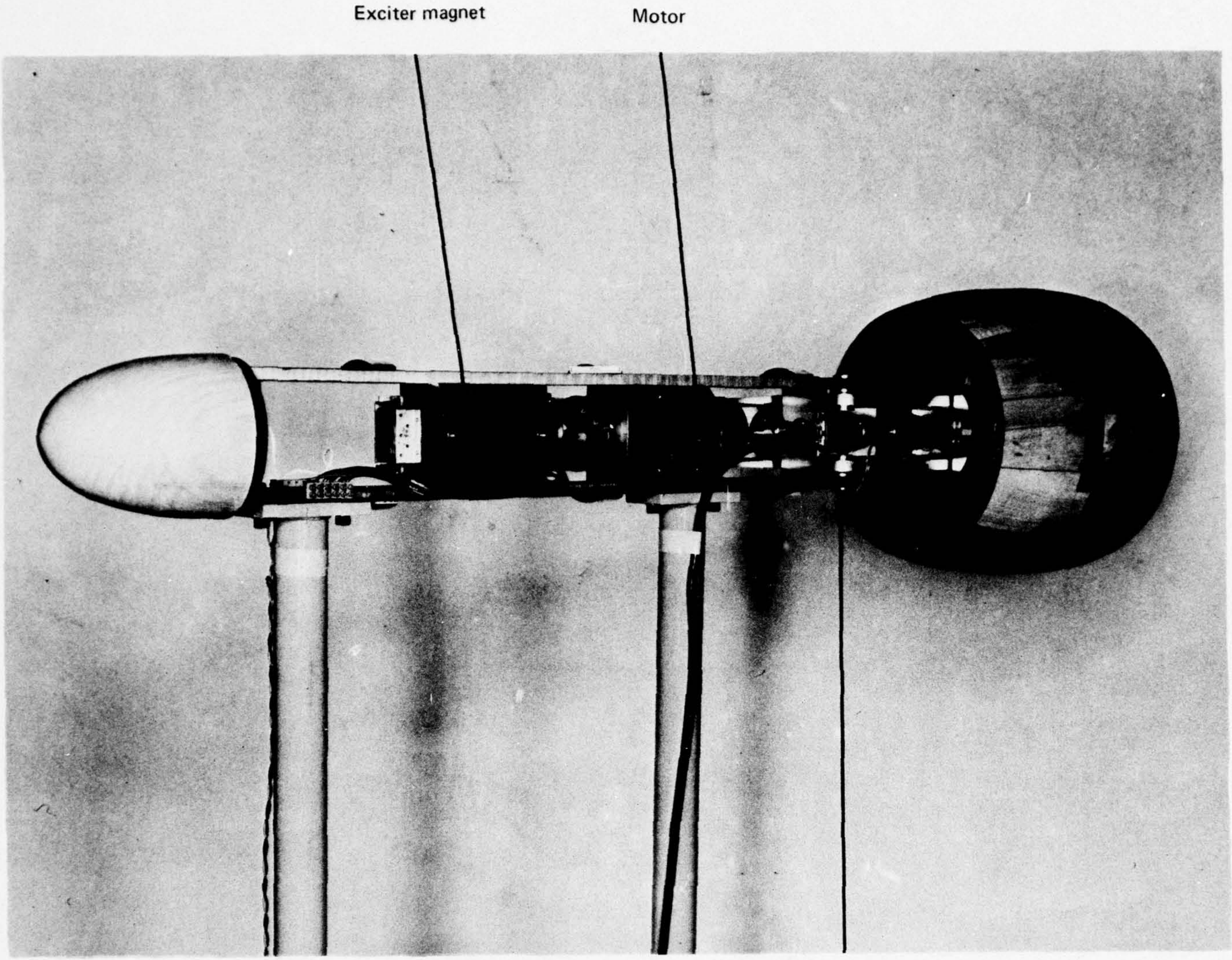


Fig.4 Rig details

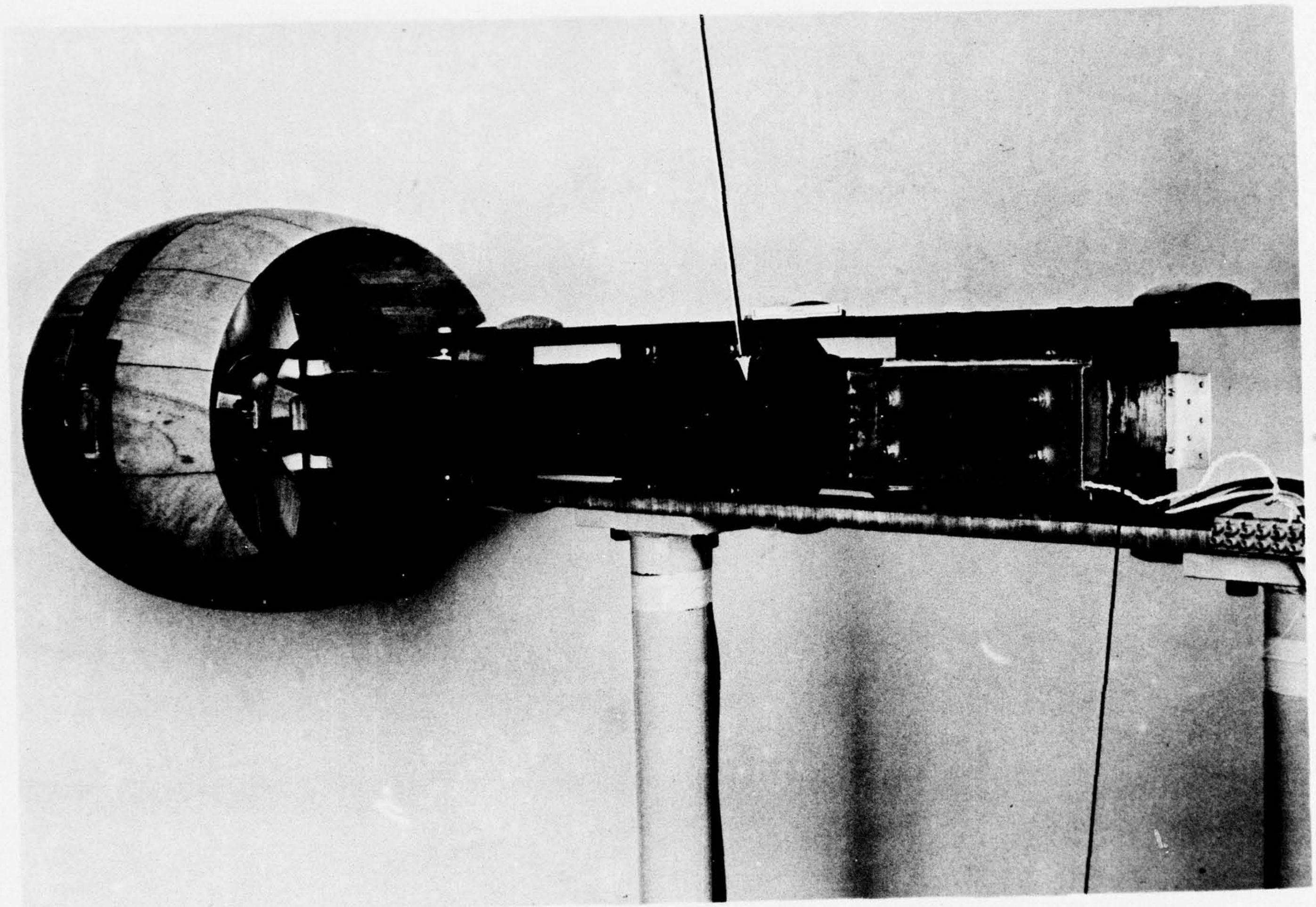
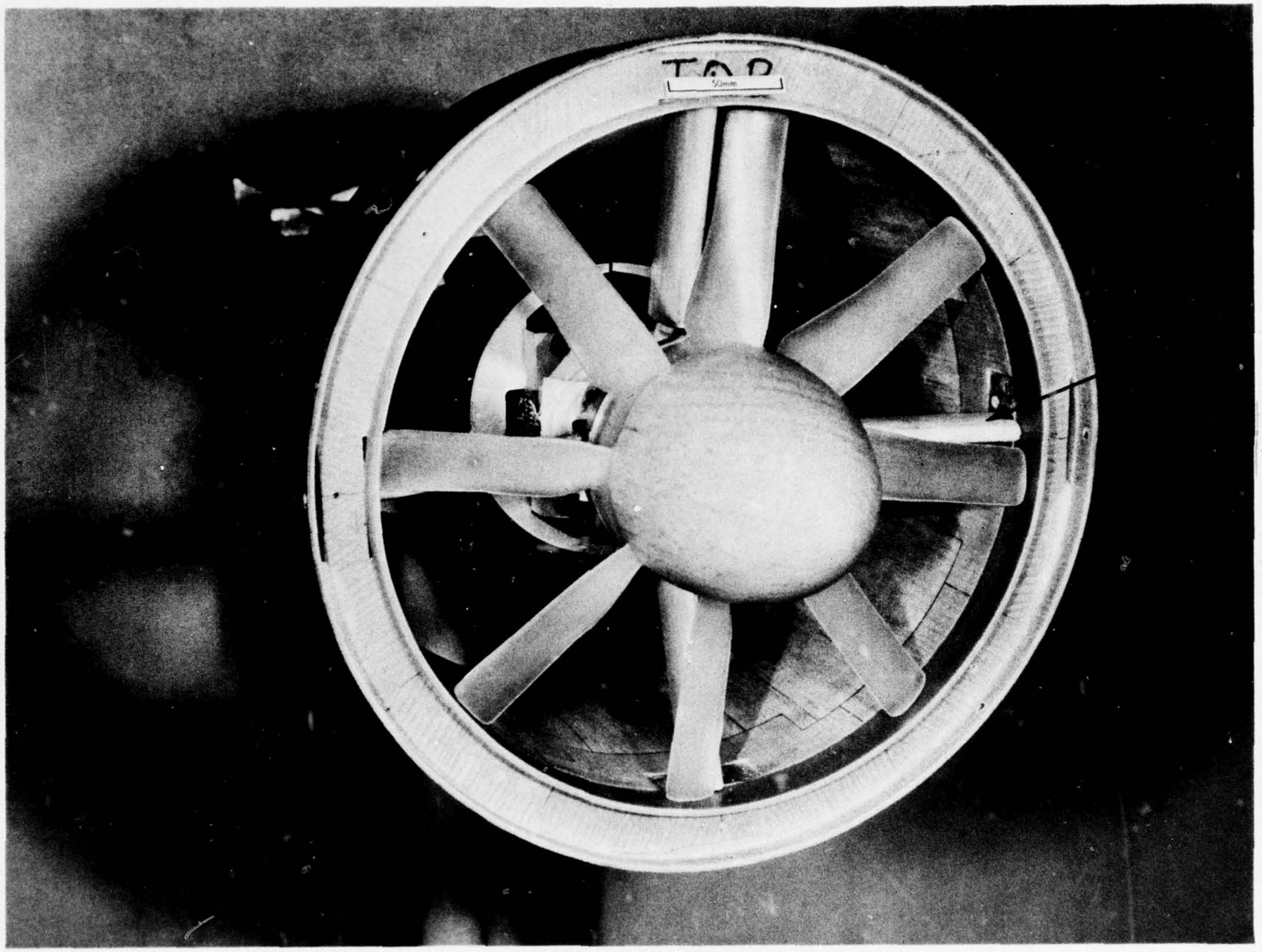


Fig.5 Rig details



Strut

Fig.6 Model details

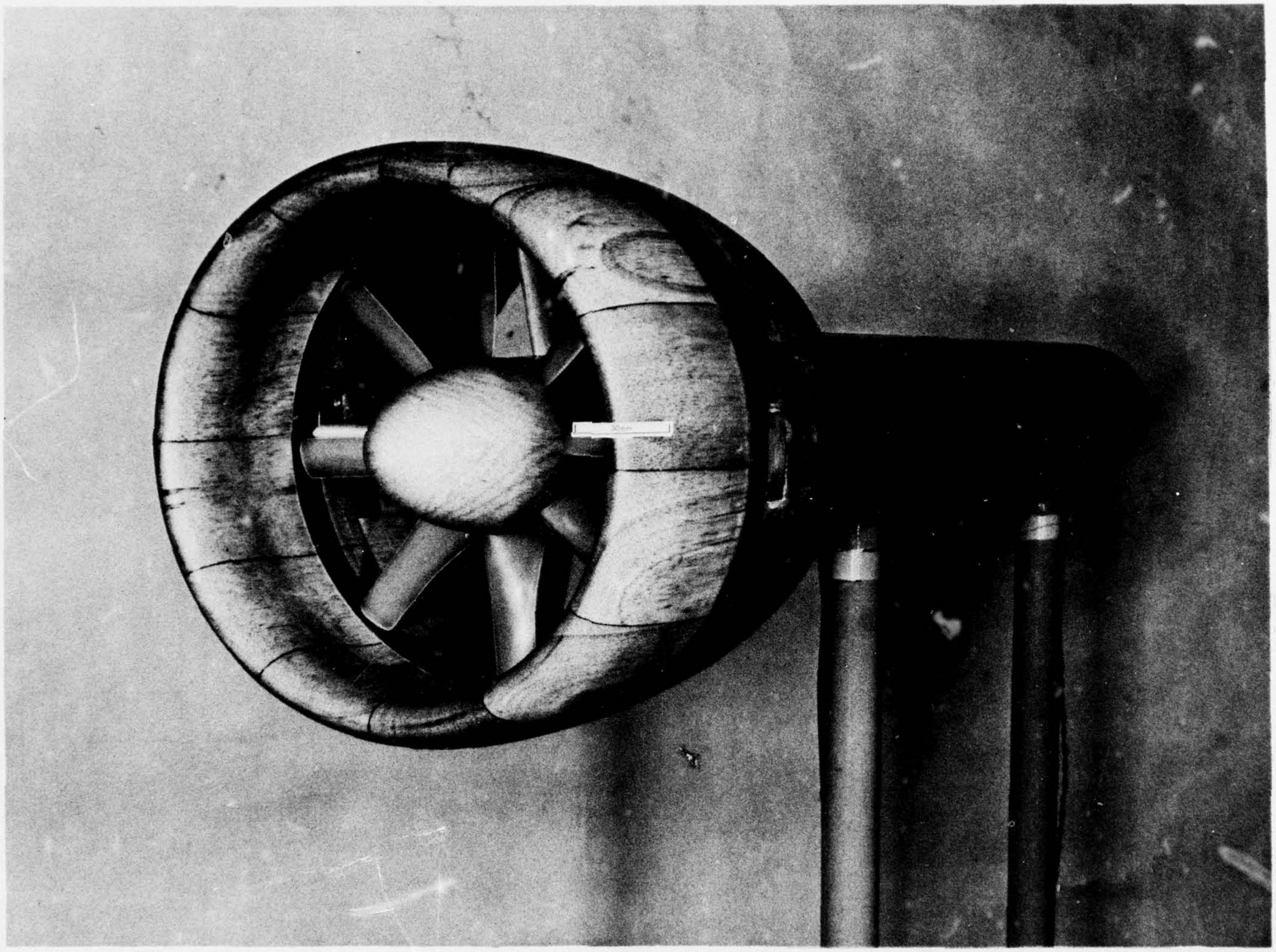


Fig.7 Medium length cowl

Fig.8

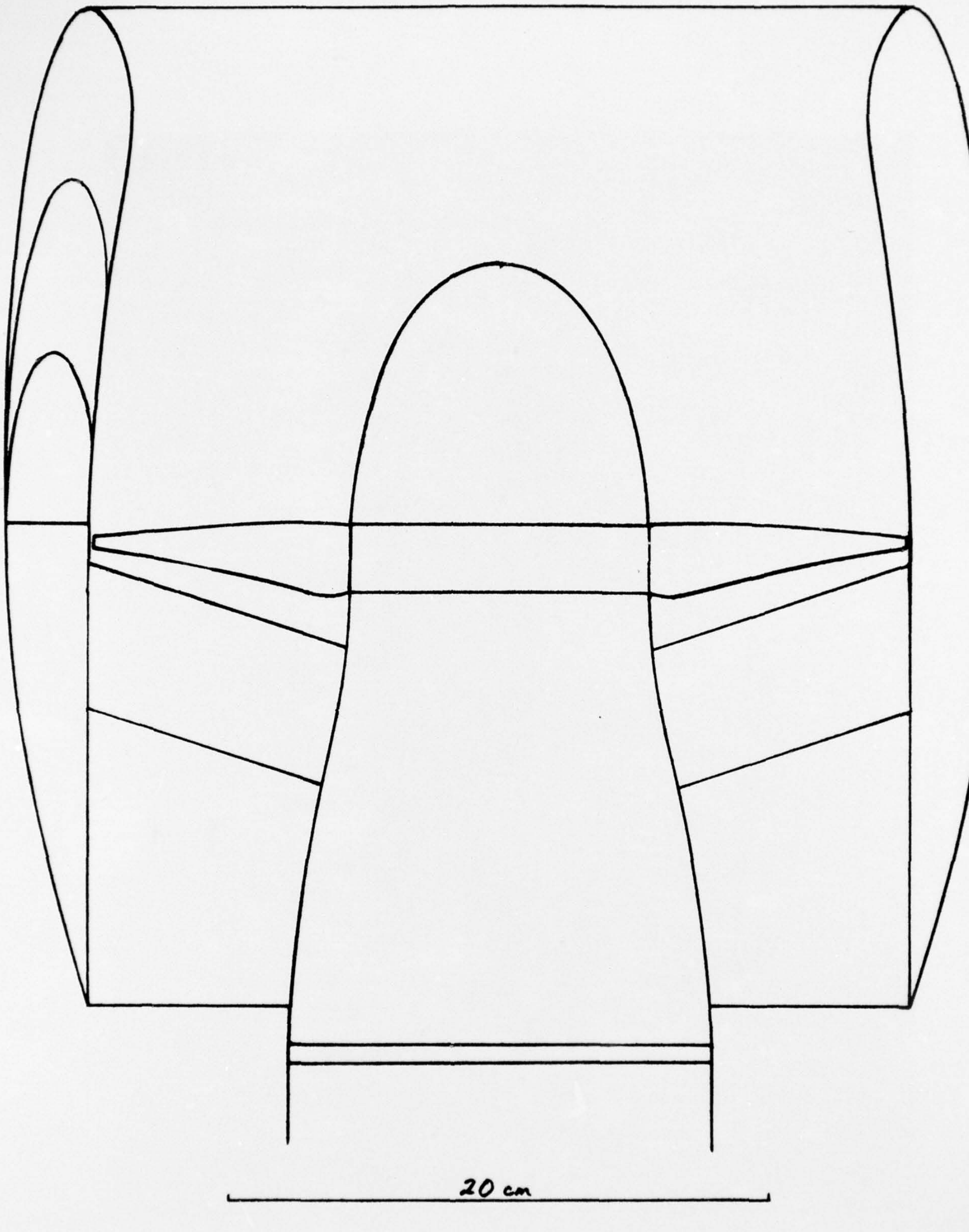


Fig.8 Model profile

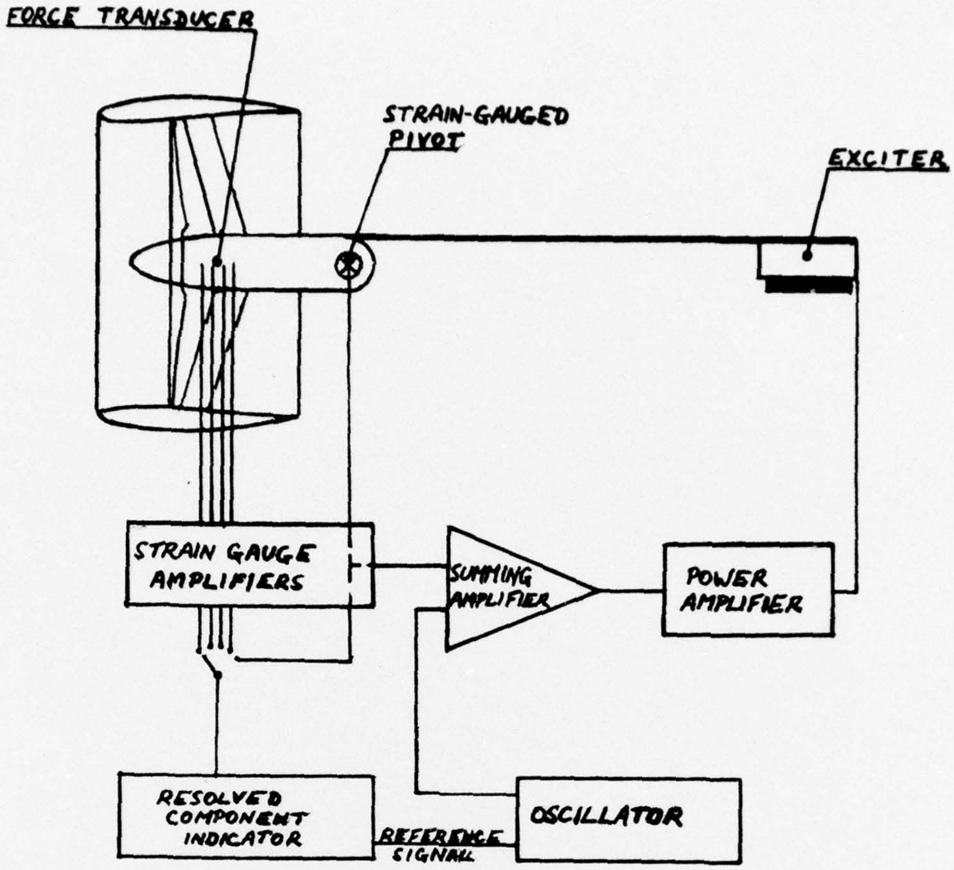


Fig.9 Instrumentation system

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

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	RAE TM Structures 889	N/A	UNCLASSIFIED

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
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7b. (For Conference Papers) Title, Place and Date of Conference

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Cansdale, R.	Gaukroger, D.R.	-	June 1976	27	5

11. Contract Number	12. Period	13. Project	14. Other Reference Nos.
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17. Abstract

A technique has been developed to measure the aerodynamic forces that are generated when a model fan-engine nacelle is oscillated in a uniform airflow. The technique enables the model to be oscillated in pitch or in yaw about one of two axis positions. A series of measurements for the four combinations of axis position and direction can be analysed to yield the aerodynamic stiffness and damping derivatives for motions of pitch, yaw, vertical and lateral translation.

A preliminary series of tests has been made using a simple model of a fan-engine in a low speed wind tunnel.

This Memorandum describes the rig and test technique, and discusses the outcome of the tests.

F5910/1

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